# IONIZATION CONSTANTS OF ACIDS AND BASES

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These $pK'_a$ values were taken from the original literature and from several extensive compilations of such data, of which the most important are

Albert, *Ionization Constants of Acids and Bases*, Methuen, London, 1962.

Bell, *The Proton in Chemistry*, 2nd ed., Cornell, Ithaca, New York, 1973.

Brown, McDaniel, and Häfliger, in Braude and Nachod, *Determination of Organic Structures by Physical Methods*, Academic Press, New York, 1955.

Kortum, Vogel, and Andrussow, *Dissociation Constants of Organic Acids in Aqueous Solution*, Butterworths, London, 1961.

Perrin, *Dissociation Constants of Organic Bases in Aqueous Solution*, Butterworths, London, 1965.

Yukawa, Ed., *Handbook of Organic Structural Analysis*, Benjamin, New York, 1965.

A particularly valuable source of dissociation constants obtained under a variety of experimental conditions is provided by Sillen L. G. and Martell, A. E., Eds., *Stability Constants*, Special Publications No. 17 and 25, Chemical Society, London, 1964 and 1971. This compilation also lists association constants of metals for a variety of inorganic and organic ligands.

The compounds selected were those which were thought most likely to be useful to biochemists and chemists and these compilations should be consulted for information on compounds which are not included here.

All values are reported as $pK'_a = -\log K'_a = 14 - pK'_b$. $K'_a$ is the ionization constant

$$\frac{[H^+][A^-]}{[HA]} \text{ or } \frac{[H^+][B]}{[HB^+]} \text{ or } \frac{[A^{n-1}][H^+]}{[HA^n]}$$

Temperatures are not indicated because variations of $pK'_a$ with temperature are generally smaller than the variations of the data from different sources for other reasons, but most of the data were obtained at or near 25°. Ionization constants which are reported as thermodynamic values at 25° are indicated with an asterisk, *, but some of these may only represent values measured at low ionic strength.

These $pK'_a$ values and a measured pH should not be used to obtain an *exact* measure of the ratio of acid to base in a given solution. Ionic strength and specific salt effects, as well as possible errors in the reported $pK'_a$ values, are likely to make such estimates inaccurate. It should be kept in mind that the effect of increasing ionic strength is generally to decrease the apparent $pK'_a$ of neutral and anionic acids and to increase the $pK'_a$ of cationic acids. These effects are particularly large for polyanions, such as phosphates.

There is some intentional redundancy in the tables to facilitate the location of listings for compounds that might be listed in several sections. The $pK'_a$ values for amines refer to the ionization of the conjugate acids of the amines except for a few nitrogen acids, which undergo an acidic ionization.

The pH of a solution at a given ionic strength and temperature is given by

$$pH = pK'_a + \log \frac{[\text{base}]}{[\text{acid}]}$$

in which the $pK'_a$ is measured under the same experimental conditions. The following relationships are useful to have readily available to estimate the ratio of acid to base at a given pH or to estimate the buffer ration of acid required to give a given pH; the compiler keeps a copy of these numbers on his desk.

| Fraction base or acid | pH | Fraction base or acid | pH |
|---|---|---|---|
| 5% or 95% | $pK'_a \pm 1.25$ | 30% or 70% | $pK'_a \pm 0.37$ |
| 10% or 90% | $pK'_a \pm 0.95$ | 35% or 65% | $pK'_a \pm 0.27$ |
| 15% or 85% | $pK'_a \pm 0.75$ | 40% or 60% | $pK'_a \pm 0.18$ |
| 20% or 80% | $pK'_a \pm 0.60$ | 45% or 55% | $pK'_a \pm 0.09$ |
| 25% or 75% | $pK'_a \pm 0.48$ | 50% or 50% | $pK'_a \pm 0$ |

## AMINO ACIDS

| Compound | $pK'_a$ | Reference |
|---|---|---|
| Alanine | 2.34, 9.69 | 6 |
| *N*-Acetyl- | 3.72 | 97 |
| Amide | 8.02* | 99 |
| 3-(2-Aminoethyldithio)- | 8.28, 9.30 | 99 |
| Carbamyl- | 3.89 | 99 |
| *N*-Ethyl- | 2.22, 10.22 | 99 |
| *N*-Methyl- | 2.22, 10.19 | 99 |
| *N*-n-Propyl- | 2.21, 10.19 | 99 |
| β-(2-Pyridyl)- | 1.37, 4.02, 9.22 | 99 |
| β-(3-Pyridyl)- | 1.77, 4.64, 9.10 | 99 |
| β-(4-Pyridyl)- | 4.85 | 99 |
| β-Alanine | 3.60, 10.19 | 6 |
| N-acetyl- | 4.44 | 129 |
| Carbamyl- | 4.49 | 129 |
| Allothreonine | 2.11, 9.01 | 99 |
| *O*-Methyl- | 1.92, 8.90 | 99 |
| γ-Aminoacetoacetic acid | 2.9, 8.3 | 99 |
| α-Aminoadipic acid | 2.14, 4.21 | 101 |
| 2-Aminobenzoic acid | 2.19, 4.95 | 99 |
| *N*, *N*-Dimethyl- | 1.4, 8.49 | 99 |
| 3-Hydroxy- | 5.19, 10.12 | 99 |
| *N*-Methyl- | 1.97, 5.34 | 99 |
| 3-Aminobenzoic acid | 3.29, 5.10 | 99 |
| 4-Aminobenzoic acid | 2.50, 4.87 | 99 |
| 4-Aminobutylphosphonic acid | 2.55, 7.55, 10.9 | 99 |
| 4-Aminobutylsulphonic acid | 10.65 | 99 |
| α-Aminobutyric acid | 2.55, 9.60 | 6 |
| Carbamoyl-α-amino-n-butyric | 3.89 | 129 |
| γ-Aminobutyric acid | 4.23, 10.43 | 6 |
| Carbamyl- | 4.68 | 129 |
| 2-Aminobutyric acid | 2.27, 9.68 | 99 |
| α-Amino-n-caproic acid | 2.33 | 129 |
| ε-Aminocaproic acid | 4.37 | 129 |
| 10-Aminodecylphosphonic acid | 8.0, 11.25 | 99 |
| 10-Aminodecylsulphonic acid | 11.35 | 99 |
| 10-Amino-*n*-dodecanoic acid | 4.648 | 99 |
| Aminoethylphosphoric acid | 2.45, 7.0, 10.8 | 99 |
| 2-Aminoethylsulphonic acid | 8.95 | 99 |
| ω-Aminoheptanoic acid | 4.50 | 136 |
| 6-Aminohexanoic acid | 4.37, 10.81 | 99 |
| α-Aminoisobutyric acid | 2.36, 10.21 | 6 |
| Carbamyl- | 4.46 | 129 |
| α-Aminoisocaproic acid | 2.33 | 129 |
| α-Aminoisovaleric acid | 2.29 | 129 |
| δ-Aminolaevulinic acid | 4.05, 8.90 | 99 |
| Aminomethylphosphonic acid | 2.35, 5.9 | 99 |
| Aminomethylsulphonic acid | 5.75 | 99 |
| α-Amino-β-methyl-n-valeric acid | 2.32 | 129 |
| 1-Aminonaphthalene-2-sulphonic acid | 1.71 | 99 |
| 2-Aminonaphthalene-1-sulphonic acid | 2.35 | 99 |
| 3-Amino-1-naphthoic acid | 2.61, 4.39 | 99 |
| 4-Aminopentanoic acid | 3.97, 10.46 | 99 |
| 5-Aminopentylsulphonic acid | 10.95 | 99 |
| 4-Aminophenylacetic acid | 3.60, 5.26 | 99 |
| 2-Aminophenylarsonic acid | 3.77, 8.66 | 99 |
| 2-Aminophenylboric acid | 4.53, 9.31 | 99 |
| β-Aminopropionic acid | 3.55*, 10.23* | 97 |
| 4-Aminosalicylic acid | 1.78, 3.63 | 99 |

* Thermodynamic value.

| Compound | $pK'_a$ | Reference |
|---|---|---|
| α-Aminotricarballylic acid | 2.10, 3.60, 4.60, 9.82 | 99 |
| α-Aminovaleric acid | 4.20 | 130 |
| 2-Anilinoethylsulphonic acid | 3.80 | 99 |
| Arginine | 12.48, 2.17, 9.04 | 6 |
| Argininosuccinic acid | >12, 1.62, 9.58, 2.70, 4.26 | 99 |
| Asparagine | 2.02, 8.8 | 6 |
| α-Hydroxy- | 2.28, 7.20 | 99 |
| β-Hydroxy- | 2.09, 8.29 | 99 |
| Aspartic acid | 2.09, 3.86, 9.82 | 99 |
| Diamide | 7.00 | 99 |
| Hydroxy- | 1.91, 3.51, 9.11 | 99 |
| Azaserine | 8.55 | 101 |
| | | 99 |
| | | 99 |
| | | 99 |
| γ-Butyrobetaine | 3.94 | 99 |
| Canaline | 2.40-, 3.70, 9.20 | 99 |
| Canavanine | 2.50, 6.60, 9.25 | 99 |
| L-Citrulline | 2.43, 9.41 | 99 |
| Creatine | 2.67, 11.02 | 6 |
| Creatinine | 4.84, 9.2 | 6 |
| Cycloserine | 4.4, 7.4 | 101 |
| Cysteine | 10.78, 1.71, 8.33 | 6 |
| Ethyl ester | 6.69, 9.17 | 99 |
| Methyl ester | 6.56, 8.99 | 99 |
| *S*-Ethyl- | 1.94, 8.69 | 99 |
| *S*-Methyl- | 8.75 | 99 |
| Cystine | 1.65, 7.85 | 6 |
| L-Cystine diamide | 5.93, 6.90 | 99 |
| 2,4-Diaminobutyric acid | 1.85, 8.28, 10.50 | 99 |
| 2,3-Diaminopropionic acid | 1.23, 6.73, 9.56 | 99 |
| 2,7-Diaminosuberic acid | 1.84, 2.64, 9.23, 9.89 | 99 |
| 3-Dimethylaminopropionic acid | 9.85 | 99 |
| Formamidinoglutaric acid | 2.7, 4.4, 11.3 | 99 |
| Formamidinoacetic acid | 2.6, 11.5 | 99 |
| Glutamic acid | 2.19, 4.25, 9.67 | 6 |
| Diethyl ester | 7.04 | 99 |
| γ-Monobenzyl ester | 2.17, 9.00 | 99 |
| α-Monoethyl ester | 3.85, 7.84 | 99 |
| γ-Monoethyl ester | 2.15, 9.19 | 99 |
| Glutamine | 2.17, 9.13 | 6 |
| Glycine | 2.34, 9.6 | 6 |
| *N*-Acetyl- | 3.67 | 99 |
| *N*,*N*-*bis*(2-Hydroxyethyl)- | 2.50, 8.11 | 99 |
| *N*-*n*-Butyl- | 2.35, 10.25 | 99 |
| Carbamyl- | 3.88* | 97 |
| Chloroacetyl- | 3.38* | 97 |
| *N*,*N*-Diethyl- | 2.04, 10.47 | 99 |
| Dihydroxyethyl- | 8.08* | 97 |
| *N*,*N*-Dimethyl- | 2.08-, 9.80 | 99 |
| *N*-Ethyl- | 2.34*, 10.23 | 99 |
| Ethyl ester | 7.83 | 99 |
| Formyl- | 3.43* | 97 |
| *N*-Isobutyl- | 2.35, 10.12 | 99 |
| Methyl ester | 7.73 | 99 |

# PEPTIDES

| Compound | $pK'_a$ | Reference |
|---|---|---|
| Ala-Ala-(LD) | 3.12, 8.30 | 27 |
| Ala-Ala-(LL) | 3.30, 8.14 | 27 |
| Ala-Ala-Ala-(3D) | 3.39, 8.06 | 27 |
| Ala-Ala-Ala-(DLL) | 3.37, 8.06 | 27 |
| Ala-Ala-Ala-Ala-(DLLL) | 3.42, 7.99 | 27 |
| Ala-Ala-Ala-(3L) | 3.39, 8.03 | 27 |
| Ala-Ala-Ala-Ala-(4L) | 3.42, 7.94 | 27 |
| Ala-Ala-Ala-(LDL) | 3.31, 8.13 | 27 |
| Ala-Ala-Ala-Ala-(LDLL) | 3.22, 7.99 | 27 |
| Ala-Ala-Ala-(LLD) | 3.37, 8.05 | 27 |
| Ala-Ala-Ala-Ala-(LLDL) | 3.24, 7.93 | 27 |
| Ala-Gly | 3.16, 8.24 | 27 |
| Ala-Gly-Gly | 3.19, 8.15 | 99 |
| Ala-Lys-Ala-(3L) | 3.15, 7.65, 10.30 | 27 |
| Ala-Lys-Ala-(LDL) | 3.33, 7.97, 10.36 | 27 |
| Ala-Lys-Ala-(LDLL) | 3.32, 8.01, 10.37 | 27 |
| Ala-Lys-Ala-(LLD) | 3.29, 7.84, 10.49 | 27 |
| Ala-Lys-Ala-Ala-(4L) | 3.58, 8.01, 10.58 | 27 |
| Ala-Lys-Ala-Ala-Ala-(5L) | 3.53, 7.75, 10.35 | 27 |
| Ala-Lys-Ala-Ala-Ala-(LDLLL) | 3.30, 7.85, 10.29 | 27 |
| β-Ala-1-methylhistidine | 2.64, 7.04, 9.49 | 99 |
| Ala-Pro | 3.04, 8.38 | 99 |
| β-Ala-Bis | 2.73, 6.87, 9.73 | 99 |
| Anserine | 7.0, 2.65, 9.5 | 6 |
| Asparaginyl-Gly | 2.90, 7.25 | 99 |
| Asp-Asp | 2.70, 3.40, 4.70 8.26 | 99 |
| α-Aspartyl-histidine | 2.45, 3.02, 6.82, 7.98 | 99 |
| β-Aspartyl-histidine | 1.93, 2.95, 6.93, 8.72 | 99 |
| Asp-Gly | 2.10, 4.53, 9.07 | 99 |
| Asp-Tyr | 2.13, 3.57, 8.92, 10.23 | 99 |
| Carnosine | 6.83, 9.51 | 6 |
| Cys-Cys | 2.65, 7.27, 9.35, 10.85 | 99 |
| Cys-Gly-Gly | 3.13, 6.36, 6.95 | 99 |
| Cys-Gly-Gly-Gly-Gly | 3.21, 6.01, 6.87 | 99 |
| L-Cystinylcystine | 1.87, 2.94, 6.53, 7.66 | 99 |
| *N,N*-Dimethylglycyl-glycine | 3.11, 8.09 | 99 |
| *N,N*-Dimethyl-leucyl-glycine | 7.78 | 99 |
| Glutaminyl-glutamic acid | 3.14, 4.38, 7.62 | 99 |
| Glutaminyl-glycine | 3.15, 7.52 | 99 |
| Glutathione | 3.59, 8.75, 9.65 | 77 |
| Glutathione, oxidized | 3.15, 4.03, 8.57, 9.54 | 77 |
| Gly-Ala (L), (D) | 3.17, 8.23 | 27 |
| Gly-Ala-Ala (LD) | 3.30, 8.17 | 27 |
| Gly-Ala-Ala (LL) | 3.38, 8.10 | 27 |
| Gly-Ala-Ala-Gly | 3.30, 7.93 | 99 |
| Gly-Asp | 2.81, 4.45, 8.60 | 99 |
| Gly-asparagine | 2.82, 7.20 | 99 |
| Gly-Gly | 3.06, 8.13 | 6 |
| Gly-Gly-cystine | 2.71, 7.94 | 99 |
| Gly-Gly-Gly | 3.26, 7.91 | 23 |
| Gly-His | 6.79, 8.20 | 99 |
| Gly-Leu | 3.10, 8.41 | 99 |
| Gly-Pro | 2.81, 8.65 | 99 |
| Gly-sarcosine | 2.98, 8.57 | 99 |
| Gly-Ser | 2.92, 8.10 | 99 |
| Gly-Ser-Gly | 3.23, 7.99 | 99 |
| Gly-Trp | 8.06 | 99 |
| Gly-Tyr | 2.93, 8.45, 10.49 | 99 |
| Gly-Val | 3.15, 8.18 | 99 |
| His-Gly | 2.36, 6.27, 8.57 | 99 |
| His-His | 5.54, 6.80, 7.82 | 99 |
| Leu-asparagine | 2.83, 8.23 | 99 |
| Leu-Tyr | 2.87, 8.36, 10.28 | 99 |
| Lys-Ala-(LD) | 3.00, 7.74, 10.63 | 27 |
| Lys-Ala-(LL) | 3.22, 7.62, 10.70 | 27 |
| Lys-Glu | 2.98, 4.47, 8.45, 11.30 | 99 |
| Lys-Lys-(LD) | 2.85, 7.53, 9.92 10.98 | 27 |
| Lys-Lys-(LL) | 3.01, 7.53, 10.05 11.01 | 27 |
| Lys-Lys-Lys-(3L) | 3.08, 7.34, 9.80, 10.54, 11.32 | 27 |
| Lys-Lys-Lys-(LDD) | 2.94, 7.14, 9.60, 10.38, 11.09 | 27 |
| Lys-Lys-Lys-(LDL) | 2.91, 7.29, 9.79, 10.54, 11.42 | 27 |
| Met-Met | 2.22, 9.27 | 99 |
| Methyl-Leu-Gly | 3.29, 7.82 | 99 |
| Phe-Ala-Arg | 2.60, 7.54, 12.43 | 99 |
| Phe-Gly | 3.13, 7.62 | 99 |
| Phenylalanylglycine amide | 6.72 | 99 |
| Pro-Gly | 3.19, 8.97 | 99 |
| Sarcosyl-Gly | 3.14, 8.66 | 99 |
| Sarcosyl-Leu | 3.15, 8.67 | 99 |
| Sarcosylsarcosine | 2.89, 9.18 | 99 |
| Ser-Gly | 3.10, 7.33 | 99 |
| Ser-Leu | 3.08, 7.45 | 99 |
| Tyr-Tyr | 3.52, 7.68, 9.80, 10.26 | 99 |
| Val-Gly | 3.23, 8.00 | 99 |

## THIOLS

| Compound | $pK_a$ | Reference |
|---|---|---|
| *N*-Acetylcysteine | 9.52 | 112 |
| *N*-Acetyl-β-mercaptoisoleucine | 10.30 | 112 |
| *N*-Acetylpenicillamine | 9.90 | 112 |
| *O*-Aminothiophenol | 6.59 | 81 |
| *p*-Chlorothiophenol | 7.50 | 81 |
| Cysteine | 1.8, 8.3, 10.8 | 23 |
| Cysteine ethyl ester | 6.53, 9.05 | 112 |
| Cysteinylcysteine | 2.65, 7.27, 9.35, 10.85 | 23 |
| 1-Diethylamino-butane-(4) | 10.1 | 5 |
| 1-Diethylamino-hexane-(6) | 10.1 | 5 |
| 1-Diethylamino-propane-(3) | 8.0, 10.5 | 5 |
| *N*-Diethyl-cysteamine | 7.8, 10.75 | 5 |
| *N*-Dimethyl-cysteamine | 7.95, 10.7 | 5 |
| *N*-Dipropyl-cysteamine | 8.00, 10.8 | 5 |
| Ethyl mercaptan | 10.50 | 81 |
| Glutathione | 2.12, 3.59, 8.75, 9.65 | 23 |
| DL-Homocysteine | 8.70, 10.46 | 112 |
| 2-Mercaptoethanesulfonate | 7.53 (9.1) | 81 |
| Mercaptoethanol | 9.5 | 23 |
| Mercaptoethylamine | 8.6, 10.75 | 23 |
| *N*-β-Mercaptoethylmorpholine | 6.65, 9.8 | 5 |
| *N*-β-Mercaptoethylpiperidine | 7.95, 11.05 | 5 |
| β-Mercaptoisoleucine | 8.10, 10.6 | 112 |
| *o*-Mercaptophenylacetic acid | 4.28, 7.67 | 59 |
| 2-Mercaptopropionic acid | 4.32, 10.30 | 153 |
| Methyl cysteine | 6.5, (7.5) | 81 |
| Methyl-[β-diethylaminoethyl]-sulfide | 9.8 | 5 |
| Methyl thioglycolate | 7.8 | 23 |
| *p*-Nitrobenzenethiol | 5.1 | 58 |
| Penicillamine | 7.90, 10.42 | 112 |
| Thiocyanic acid | −1.84 | 104 |
| Thioglycolic acid | 3.67, 10.31 | 23 |
| Thiophenol | 7.8, 6.52 | 59, 81, 82 |
| Pentafluoro- | 2.68 | 155 |
| *p*-Me- | 6.82 | 157 |
| *p*-OMe- | 6.77 | 157 |
| *m*-Me- | 6.66 | 157 |
| *m*-OMe- | 6.38 | 157 |
| *p*-Cl- | 6.13 | 157 |
| *p*-Br- | 6.02 | 157 |
| *m*-Cl- | 5.78 | 157 |
| *p*-COMe- | 5.33 | 157 |
| *m*-$NO_2$- | 5.24 | 157 |
| *p*-$NO_2$- | 4.71, 4.50 | 157 |
| *l*-Thio-D-sorbitol | 9.35 | 81 |
| *N*-Trimethyl cysteine | 8.6 | 23 |

| X = | −H | $-S^-$ | −SH |
|---|---|---|---|
| $X(CH_2)_2SH$ | 12.0 | 13.96 | 10.75 |
| $X(CH_2)_4SH$ | 12.4 | 13.25 | 11.50 |
| $X(CH_2)_3SH$ | — | 13.24 | 11.14 |
| $X(CH_2)_5SH$ | — | 13.27 | 11.82 |

| Mercaptans, RSH<br>R | $pK_a$ | Reference |
|---|---|---|
| $C_6H_5CH_2$- | 9.43 | 82 |
| $HOCH_2CH(OH)CH_2$- | 9.51 | 82 |
| $CH_2{=}CHCH_2$- | 9.96 | 82 |
| *n*-$C_4H_9$- | 10.66 | 82 |
| *t*-$C_5H_{11}$- | 11.21 | 82 |
| $C_2H_5OCOCH_2$- | 7.95 | 82 |
| $C_2H_5OCH_2CH_2$- | 9.38 | 82 |
| $HOCH_2CH(OH)CH_2$- | 9.66 | 82 |
| *n*-$C_3H_7$- | 10.65 | 82 |
| *t*-$C_4H_9$- | 11.05 | 82 |
| $(CH_3)_2CH$- | 10.86* | 103 |
| $(CH_3)_3C$- | 11.22* | 103 |
| $HOCH_2CH_2$- | 9.72 | 103 |
| $CH_3CONHCH_2CH_2$- | 9.92 | 103 |
| $^-OCOCH_2$- | 10.68* | 103 |
| $^-OCOCH_2CH_2$- | 10.84* | 103 |
| *o*-$^-OCOC_6H_4$- | 8.88* | 103 |
| *p*-$^-OCOC_6H_4$- | 5.80* | 103 |
| $CH_3CO$- | 3.62* | 103 |

* Thermodynamic value.